Mechanical Tensile Testing of Hiperco 50A at Cryogenic Temperature

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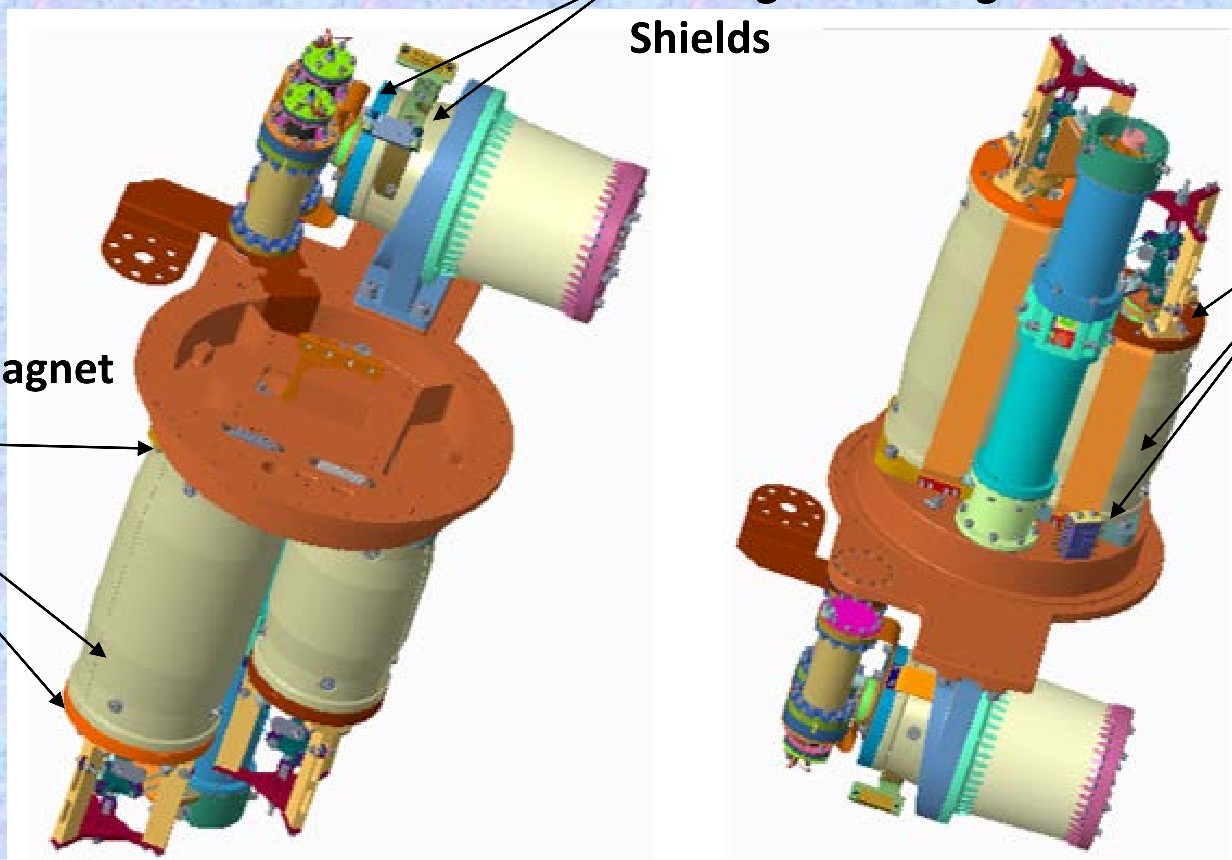
INTRODUCTION

1) Hiperco 50A is a highly desired material for use in cryogenic applications, specifically for adiabatic demagnetization refrigerators (ADRs) due to its magnetic field shielding capabilities.
2) Hiperco 50A is used to provide magnetic shielding to the ADR stages in NASA's Resolve instrument.



Hiperco 50A Material

1) Hiperco 50A is an iron-cobalt-vanadium alloy known for its high magnetic saturation properties and high strength.
2) **Applications**: transformers, manufacture of rotor and stator laminations in motors, ADR magnetic shielding.
3) Summary of room temperature properties (properties gathered from Carpenter Specialty Alloys data sheet)

Density (lb/in^3) (kg/m^3)	Tensile Modulus (Msi) (GPa)	Ultimate Tensile Strength (ksi) (MPa)	Elongation To Failure (%)	Yield Strength (ksi) (MPa)
0.293 8120	30 207	115 792	8.0	57 393

Table 2: Mechanical Properties of Hiperco 50A at room temperature

4) **Concerns**: It is not known if Hiperco 50A becomes increasingly brittle at cryogenic temperatures. It is also unknown if the ultimate tensile strength, tensile modulus, and yield strength will remain the same, increase or decrease. This information is critical to Hiperco 50A applications at cryogenic temperature.

Hiperco 50A Specimen Development

- Requirements
  - The specimen design was guided by ASTM Standard E8 and 1450. **Mechanical failure must occur in the gage length section**
  - Specimens must receive the same annealing schedule that the flight hardware in the Resolve ADR receives.

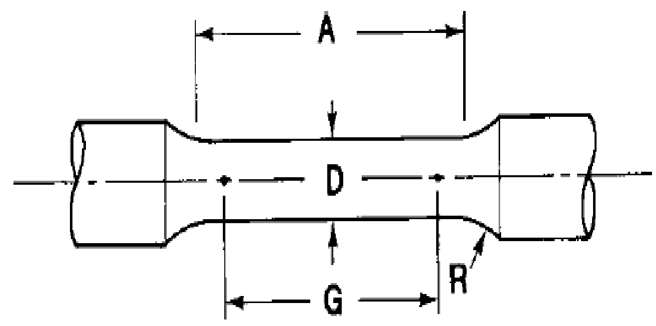
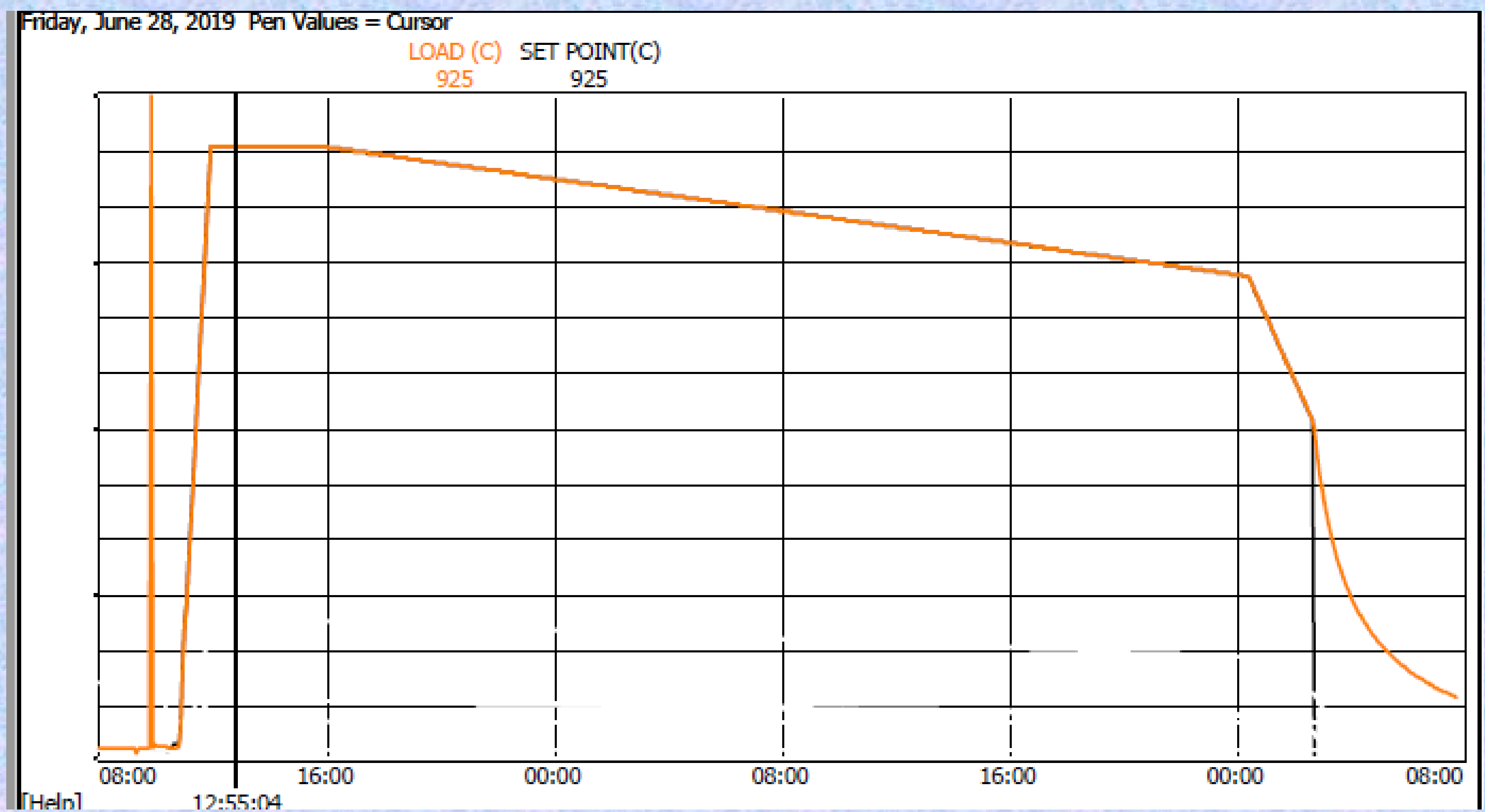


FIG. 4 Round Bar Specimen Configuration (see Table 1)

(b)

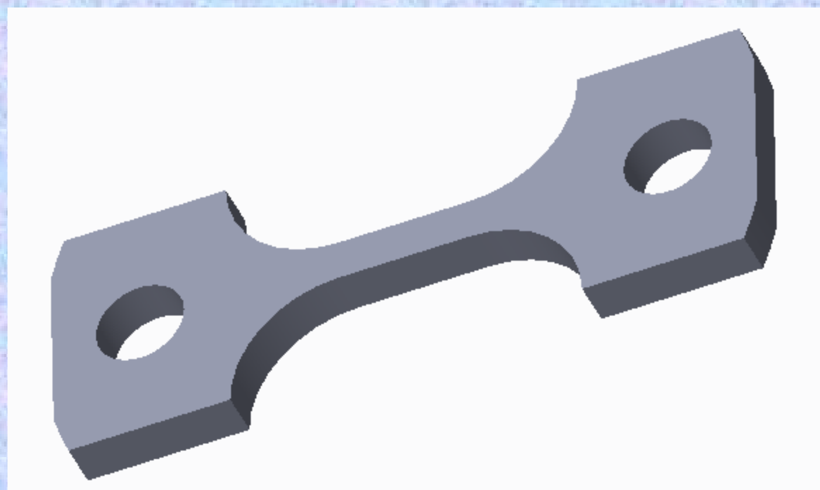
U.S. Customary Versions G/D ratio = 4 (dimensions, in.)	Standard Specimen	Standard Small Specimen
Nominal Diameter	0.5	0.25
G, gage length	2.000 ± 0.005	1.000 ± 0.005
D, diameter	0.500 ± 0.010	0.250 ± 0.005
R, fillet radius	0.375	0.1875
A, reduced section	2.25	1.25

Hiperco 50A Specimen Annealing



Hiperco 50A Specimen Development

- The following pinned specimen was designed
- The test fixtures for grabbing the specimens are owned by the mechanical testing lab. They are approved for 20,000 lbs of force
- The specimens were analyzed and approved to break in the gage length
- Specimens were cut from titanium Hiperco 50A billet material provided by code 552



Specimen Design

Broken Specimen
in gage section

Hiperco 50A Tensile Test Results Engineering Stress vs. Strain

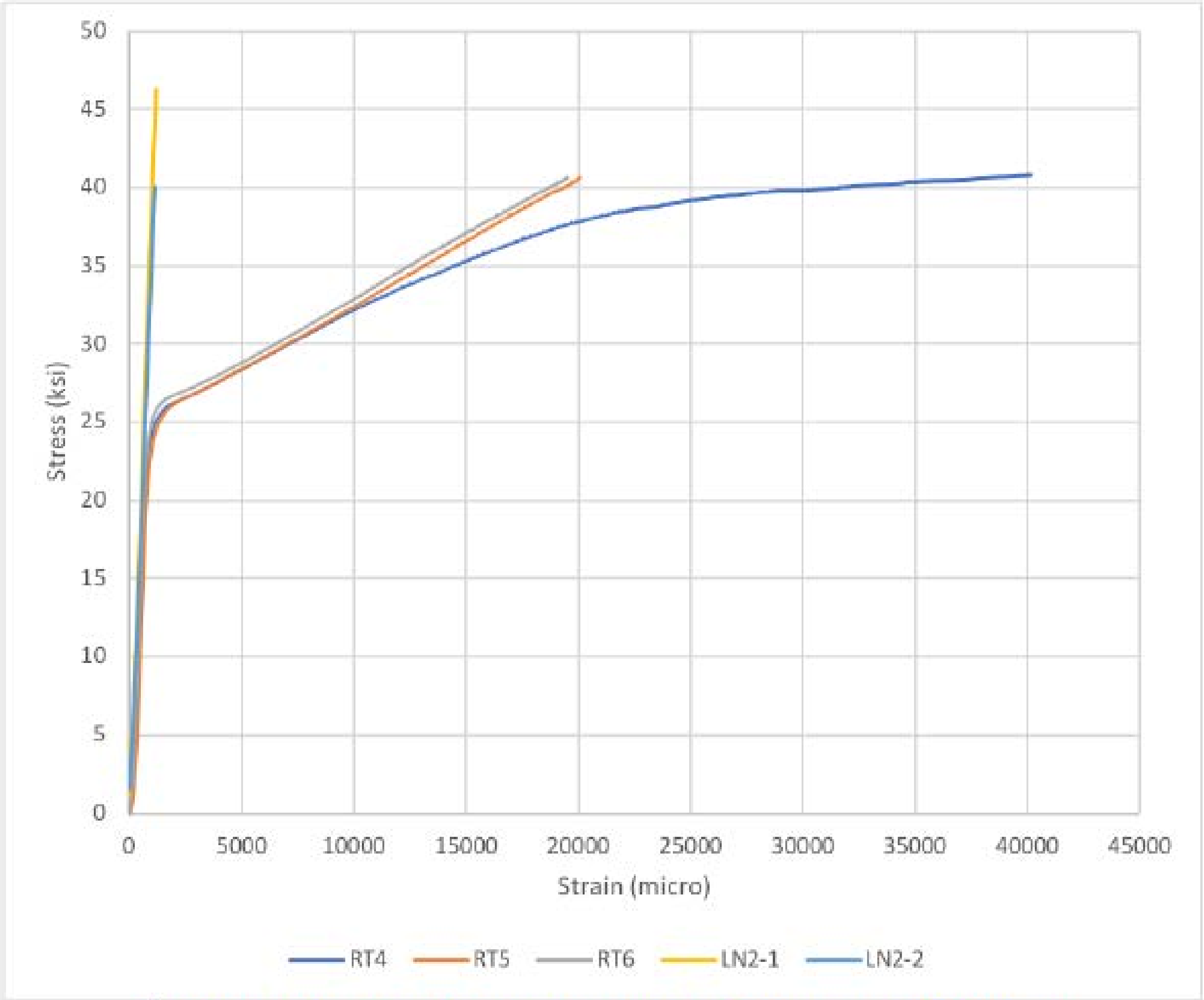


Figure 1. Stress vs Strain Curves of Room Temperature and Cryogenic Hiperco 50A Coupons.

Hiperco 50A Mechanical Properties

Table 1. Room Temperature Hiperco 50A Mechanical Properties (Fracture Initiation within gage).

	Max Load[1] (lbs)	Tensile Strength (ksi)	Max Strain (%)	Modulus (Msi)	Yield Strength[2] (ksi)
RT4	2551	40.8	4.01	34.6	26.8
RT5	2540	40.64	2.01	34.8	26.9
RT6	2745	43.92	2.42	36.7	26.9
Avg	2612	41.8	2.81	35.4	26.9
Avg Previous Lot	2573	40.6	-	-	28.2
StDev[3]	115	1.8	1.06	1.16	0.03
COV	4.4%	4.4%	37.7%	3.3%	0.1%

1.) Uncertainty is ±0.5% of measured value
2.) Determined at 0.2% offset
3.) One standard deviation

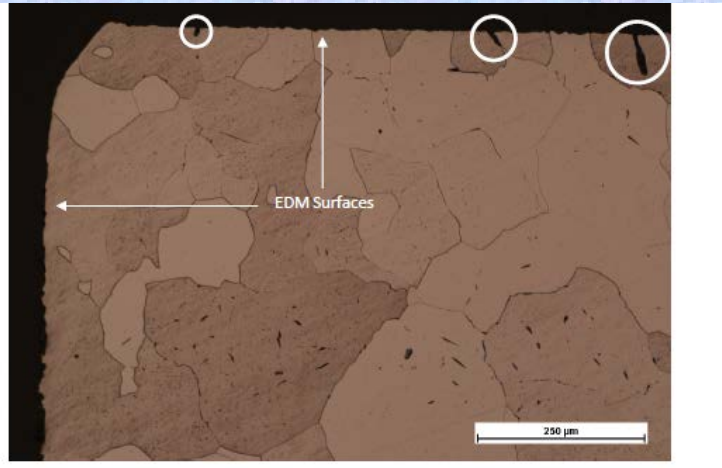
Table 2. Hiperco 50A Mechanical Properties at LN2 Temperature (Fracture Initiation at Fixture Hole ID).

	Max Load[1] (lbs)	Tensile Strength (ksi)	Max Strain (%)	Modulus (Msi)	Yield Strength[2] (ksi)
LN2-1	2936	46.2	0.129	34.7	-
LN2-2	2500	40.1	0.115	33.4	-
LN2-3	2645	42.3	0.121	-[4]	-
Mean	2612	42.9	0.122	-[5]	-
StDev[3]	115	3.1	0.007	-[5]	-
COV	4.4%	7.2%	5.5%	-[5]	-

1.) Uncertainty is ±0.5% of measured value
2.) For linear elastic materials, yield strength is the same as tensile strength.
3.) One standard deviation
4.) No raw data file for LN2-3, and Modulus could not be reported
5.) Due to only two data points, average, standard deviation, and COV not calculated

Complications with LN2 Samples

- All 3 Hiperco 50A samples that were tensile tested at 77 K broke at the pinned section rather than the gage.
- Analysis confirmed flaws in the material where the failure propagated from.

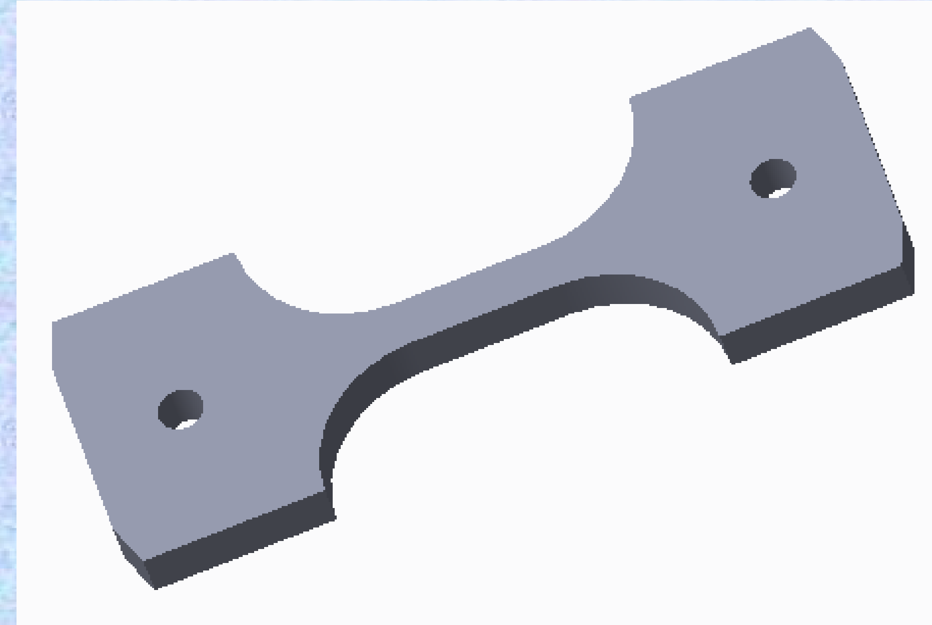


Surface Flaws from EDM

Specimen broken at LN2 Temp

New Specimen Designed for LN2 Testing

- Pin diameter reduced by 50%



Specimen Design (reduced pin hole)

Hiperco 50A Reduced Pin Hole Test Results
Engineering Stress vs. Strain

Figure 1. Stress vs Strain Curves of Room Temperature and Cryogenic Hiperco 50A Coupons.

Hiperco 50A Mechanical Properties From Reduced Specimens

Table 1. Room Temperature Hiperco 50A Mechanical Properties (Fracture Initiation within gage).

	Max Load[1] (lbs)	Tensile Strength (ksi)	Max Strain (%)	Modulus (Msi)	Yield Strength[2] (ksi)
RT4	2551	40.8	4.01	34.6	26.8
RT5	2540	40.64	2.01	34.8	26.9
RT6	2745	43.92	2.42	36.7	26.9
Avg	2612	41.8	2.81	35.4	26.9
Avg Previous Lot	2573	40.6	-	-	28.2
StDev[3]	115	1.8	1.06	1.16	0.03
COV	4.4%	4.4%	37.7%	3.3%	0.1%

1.) Uncertainty is ±0.5% of measured value
2.) Determined at 0.2% offset
3.) One standard deviation

TO BE DETERMINED

Table 2. Hiperco 50A Mechanical Properties at LN2 Temperature (Fracture Initiation at Fixture Hole ID).

	Max Load[1] (lbs)	Tensile Strength (ksi)	Max Strain (%)	Modulus (Msi)	Yield Strength[2] (ksi)
LN2-1	2936	46.2	0.129	34.7	-
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LN2-3	2645	42.3	0.121	-[4]	-
Mean	2612	42.9	0.122	-[5]	-
StDev[3]	115	3.1	0.007	-[5]	-
COV	4.4%	7.2%	5.5%	-[5]	-

1.) Uncertainty is ±0.5% of measured value
2.) For linear elastic materials, yield strength is the same as tensile strength.
3.) One standard deviation
4.) No raw data file for LN2-3, and Modulus could not be reported
5.) Due to only two data points, average, standard deviation, and COV not calculated

Conclusions

- Hiperco 50A
  - UTS increases at cold temperatures
  - Yield strength increases at cold temperatures
  - Break strength increases at cold temperatures
  - **Material becomes brittle. Crack propagation is an issue.**
    - Strain to failure was greatly reduced.
    - Any flight parts made from this material must be screened for cracks and flaws.